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1. Introduction and Executive Summary

This study was undertaken to determine the single event transient distribution of a transimpedance amplifier configuration of the AD8041 Operational Amplifier. The AD8041 is made in a bipolar technology and the application of interest has a bipolar supply of ±5 V. The device was monitored for transient events on the output voltage during exposure to a heavy ion beam at Lawrence Berkeley National Laboratory's (LBNL) 88-inch Cyclotron on November 11, 2022. Destructive effects were not observed. Transient events were observed at a Linear Energy Transfer threshold (LET_{th}) of 8.5 $MeVcm^2mg^{-1}$. Both positive and negative polarity transients were observed. Maximum observed transient amplitude was 3.2V, however, transients similar in amplitude are very unlikely even with the worst-case LET. The 90th percentile of all transients was less than 1.88 V amplitude. Observed transient event saturation cross section was 5 $x10^{-5}$ cm^{-2} at an LET of 49.5 $MeVcm^2mg^{-1}$. It is noteworthy that these results apply only to the transimpedance amplifier configuration of the AD8041 and may not be applicable to other operational amplifier configurations.

2. Device Description

The AD8041 is a low power voltage feedback operational amplifier designed to operate on +3 V, +5 V, and ±5 V supplies with rail-to-rail output swing, fast settling time, and gain-bandwidth product of 160 MHz. The lot date code (LDC) of the devices tested was 2112. The test devices were provided in an 8-lead standard small outline package (R-8) surface mount plastic encapsulated package.

Table I. Part description

Part Number	AD8041ARZ
Manufacturer	Analog Devices, Inc.
Lot Date Code	2112
Quantity Tested	3, plus 2 controls
Part Function	Operational Amplifier
Part Technology	Bipolar
Package	R-8

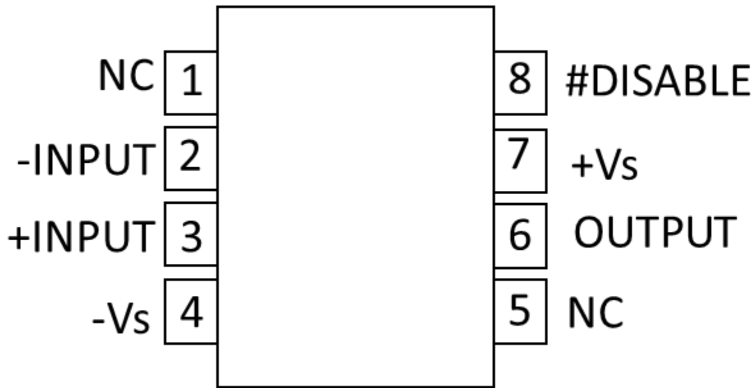

Figure 1 – Pinout Diagram of AD8041

3. Test Setup

The test setup consisted of the test board mounted in front of the LBNL heavy ion beam port, a host PC running a controller/monitor LabVIEW oscilloscope program with channels set up to trigger on a transient amplitude. Sample speed was set at 100 MS/s. Signal termination was an estimate of the application with 50 Ω series resistance at the output of the op amp circuit. The signal ran over a 50 Ω impedance cable to the oscilloscope. The 50 Ω terminated oscilloscope channel monitored the signal for transients. The oscilloscope was with transient full-width half-max (FWHM) timing threshold greater than 50 ns and amplitude threshold greater than 60 mV.

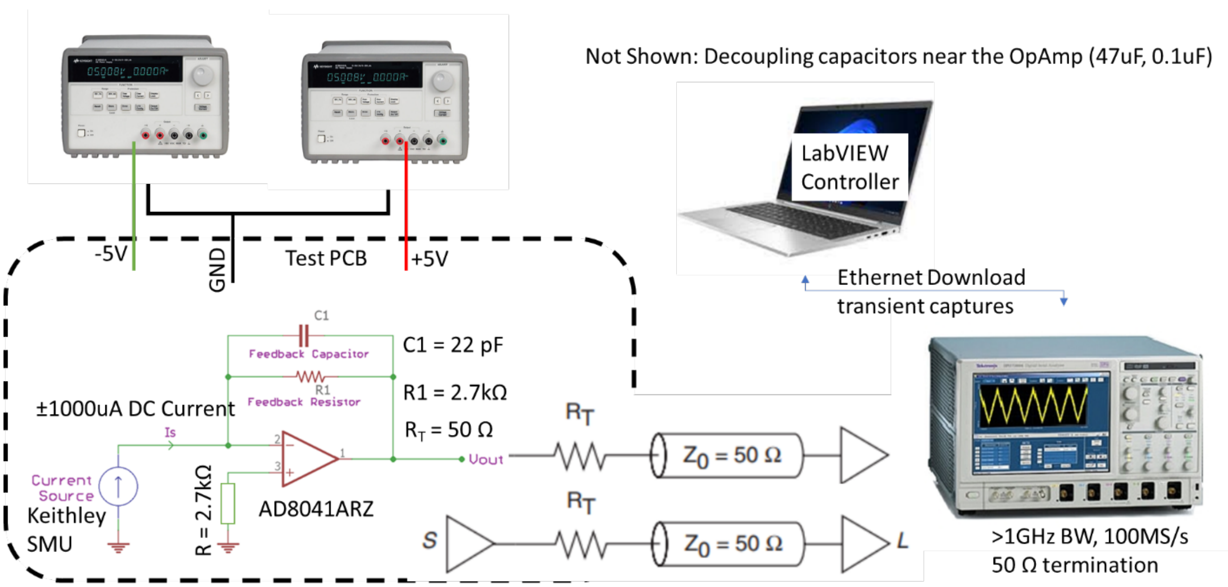

Figure 2. Notional Test Setup Diagram

The AD8041 was set up in a transimpedance amplifier configuration with a constant DC current into the inverting input between 0 and 10 µA from a Keithley SourceMeter to confirm functionality of the operational amplifier circuit. The inverting input was grounded to reduce noise at the time of testing. The non-inverting input was pulled down to ground by a 2.7 kΩ resistor. The supply voltages were set to ±5V. Decoupling capacitors on the power rails were 47 µF and 0.1 µF. Feedback capacitor was 22 pF.

4. Test Facility

Facility: Lawrence Berkeley National Laboratory (LBNL), 88-inch cyclotron

Type of Radiation: Heavy ions

Facility Configuration: 16 MeV/amu tune

Flux: $1x10^4\ cm^{-2}s^{-1}$ to $1x10^6\ cm^{-2}s^{-1}$

Fluence: Testing was conducted to at least $1x10^6 cm^{-2}$ at each test condition for three devices. Most test runs were conducted to at least $1x10^7 cm^{-2}$.

Beams / LET:

Ion Species	Angle (°)	LET_{eff} ($MeVcm^2mg^{-1}$)
Ar	0	8
Ar	45	12.5
Cu	0	19
Kr	0	30
Ag	0	46
Kr	45	50

5. Test Conditions

Temperature: 25° C

In-Air or Vacuum: In-air, air gap ~10 mm to ~50mm (at angle)

Supply Voltages: ±5 V

6. Test Methods

- ASTM Guide F1192-00-Standard Guide for the Measurement of Single Event Phenomena (SEP) Induced by Heavy Ion Irradiating of Semiconductor Devices.
- JEDEC 57 Heavy Ion Testing Guideline.

7. Test Performance and Results

Personnel: Matt Joplin (NASA GSFC), Michael Campola (NASA GSFC), and Jonathan Barth (NASA GSFC)

The AD8041 operational amplifier integrated circuit chips were decapsulated to expose the silicon die to allow exposure to the heavy ion beam. These decapsulated devices were electrically checked out prior to exposure to ensure functionality. The transimpedance amplifier circuit with the AD8041 decapsulated device acting as the op amp was set up in front of the beam port in air at about 10 mm of distance.

Testing started with the first available ion, Krypton, at normal incidence with rising edge triggering and falling edge triggering to capture positive and negative transients. Oscilloscope was set up to capture 1000 samples in a window of 100 MS/s with a maximum amplitude that extended to the rail voltages, namely +5V and -5V. The circuit was designed such that the stable region was between +1V and -1V. In other words, regardless of the current at the input of the inverting port of the operational amplifier, the output would never exceed these values under nominal operating conditions.

Once operation of the AD8041 was confirmed with a small current into the inverting input, the input was grounded to eliminate any sources of noise that would hinder the observation of transients. Hundreds of transients were observed at Krypton, and no destructive effects were observed up to a fluence of 1 $x10^{7}$ cm^{-2} particle fluence. The negative transient behavior bounded the positive transient behavior in that they had greater probability of occurring, greater amplitudes, and longer durations, so the remainder of testing was done with a falling edge trigger on the oscilloscope captures.

The LET was gradually reduced to the point that one or no events were observed over the course of a $1x10^{7}$ cm^{-2} particle fluence, this would indicate the transient threshold. Threshold was observed with Argon ion species at normal incidence at approximately 10mm of air gap which produces an approximate LET of 8 $MeVcm^{2}mg^{-1}$ at the surface of the active die.

Upon observation of the threshold, the transient threshold observation was repeated with a second device and LET was gradually increased to observe saturation cross section. Cross section for any transient event was observed to be very low – saturation cross section was approximately $3x10^{-5}$ cm^{2} to $5x10^{-5}$ cm^{2} for LET values above 45 $MeVcm^{2}mg^{-1}$.

The observations of threshold and saturation cross section values were repeated with a third device before concluding transient testing.

Apart from the threshold test runs, a sample size of greater than 100 transients were captured for each LET.

The Weibull fit of the data is displayed in Figure 3.

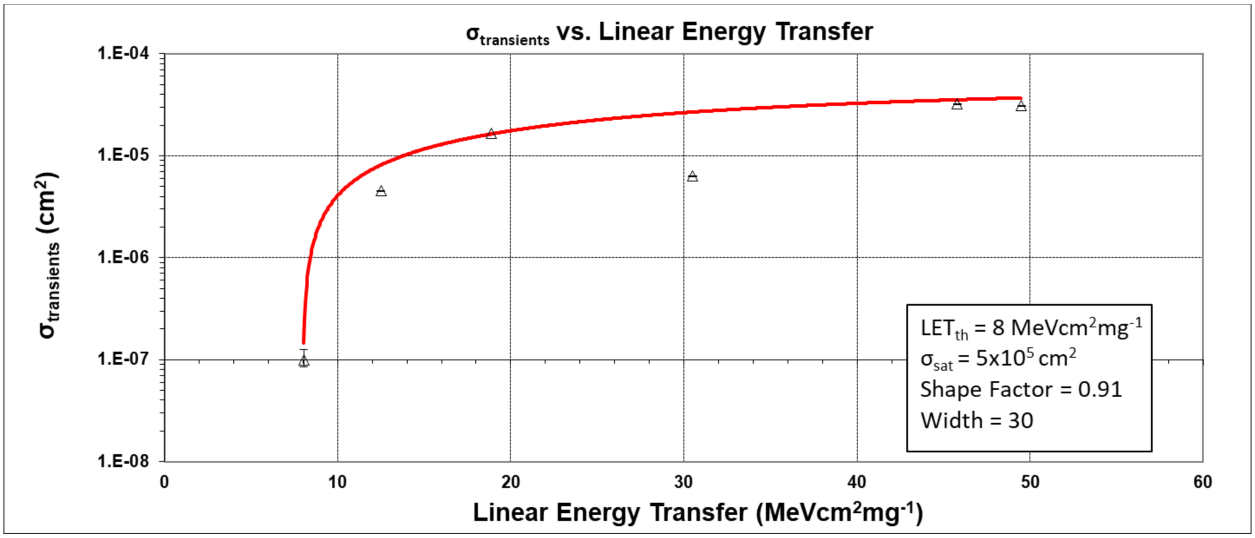

Figure 3 - Weibull fit of all AD8041 single event transients

8. Discussion and Usage Limitation

The AD8041 transient event rate was determined to be low enough to meet requirements of the project, so no further analysis of transient criticality was performed. However, this determination is specific to the application of the device, so the broader applicability of these results is limited and should be used with caution.

9. Equipment List as Tested

MFG and P/N	Function
Agilent 6700	Power supply module
Agilent 6700	Power supply module
LabView PC	Power supply controller
Tektronix MSO5104	Oscilloscope
LabView PC	Oscilloscope controller
Keithley 2400	SourceMeter Unit (functional testing only)